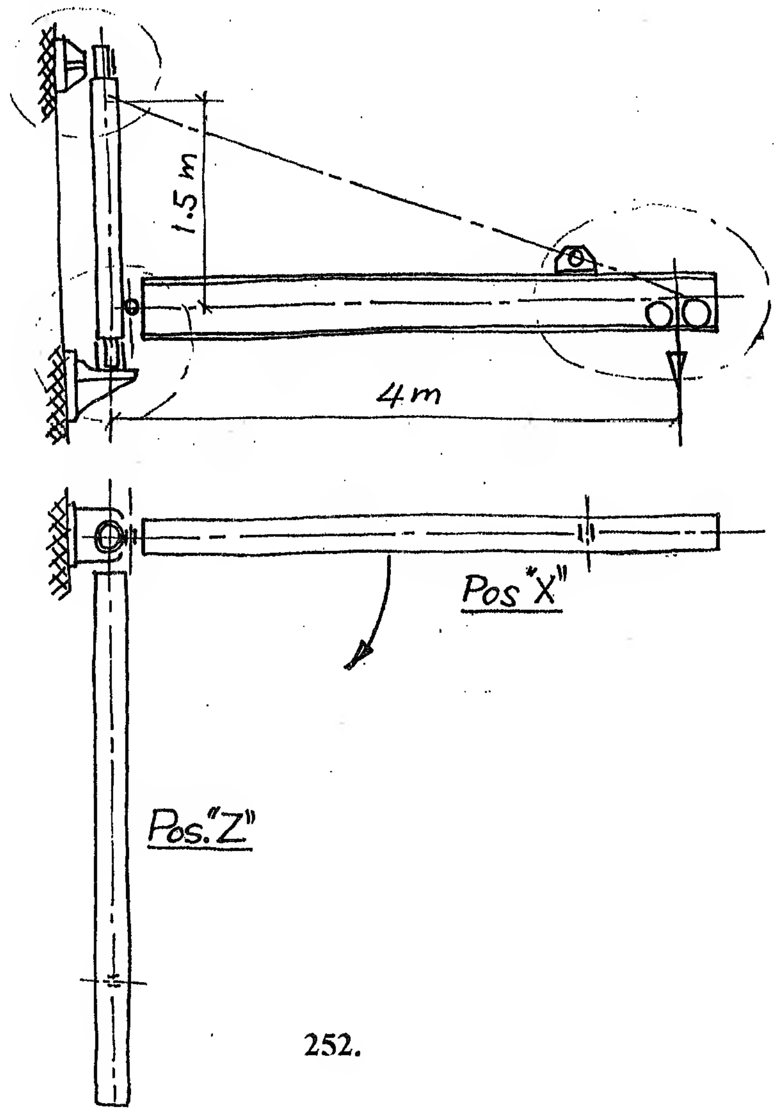
Wall Jib-Crane [S.W.L. 15 kN, 4 m reach]

Attatched are the principal design calculations for a wall jib crane SWL. 15 kN, 4 m. reach when the beam is in Pos "X".

Guided by the sketches, diagrams, calculations, assumptions and the selected materials of different items and parts, it is required to:

1- Check the wall brackets fixation, dimensions and select the suitable material when the crane is in P[illegible]

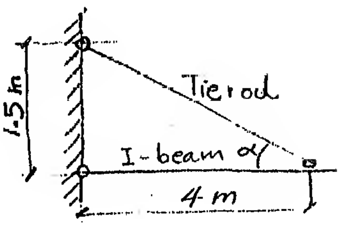
2- Construct the encircled zones giving all th[illegible] details and showing the trolley at the two extreme load positions on the beam.



15 kN, 4 m outreach Jib Crane.

S.W.L. = 15 kN

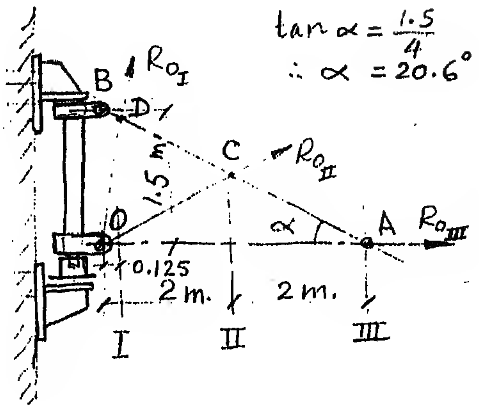
Required I-beam size:



Three positions of loading along the beam should be considered; namely I, II, III

$\tan\alpha = \frac{1.5}{4}$

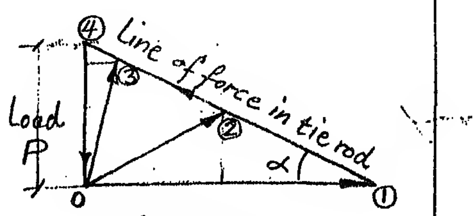
$\therefore \alpha = 20.6°$



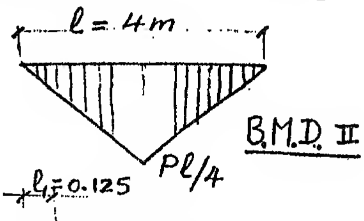
Two test conditions:

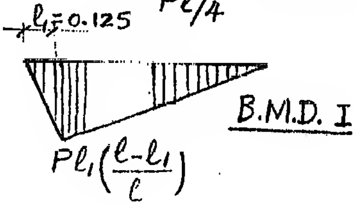
1) static loads

(1-1) Test load = 1.4 S.W.L. in position (II), Successful if δ = beam deflection is less than $\frac{1}{700}$ * loaded span taking into consideration the self weight values.



(1-2) Test Load = 1.2 S.W.L. in position (I), to check that no relative displacement between supports occurs.





(1-3) Test load = 1.2 S.W.L. in position (III), "OA" should be horizontal. If "A" gets below horizontal, correction should be done using the turn-buckle located on the tie rod.

The three cases of static loading represent the technique of checking the structure integrity.

Bending stresses in the I-beam;

1) B.M. at test $= Pl/4 = \frac{21*4}{4} = 21$ kN.m

$$\sigma_b = \frac{M}{Z_{xx}} = \frac{21*10^6}{278000} = 75.5 \quad N/mm^2$$

Material: Structural st 37, $\sigma_{y_t} = 200$ N/mm^2

margin of safety at test $= 2.65 > 1.2$

2) B.M. due to S.W.L. $= \frac{15*4}{4} = 15$ kN.m.

$$\sigma_{b_{SWL}} = \frac{15 \times 10^6}{278000} = 54 \quad N/mm^2$$

margin of safety at S.W.L. $= \frac{200}{54} = 3.7$

Force Analysis:

There are three joints "O", "A", "B".
The carried wt. is allways vertical, the force along AB is allways tension in the direction of the tie rod and the reaction through "O" allways pass through the point of intersection between the line of action of the carried wt. and the line of action of the tie rod tension.

Three cases will be examined:

at test load	= 1.4 SWL.	Pos. II
at test load	= 1.2 SWL.	Pos. I & III
at SWL.	= 15 kN	Pos I, II, III

Note: Pos. I is only 0.125 m from O while the full span is 4 m. Hence, consider the load at Pos. I is directly on the hinge. The 0.125 m is half the length of the trolley.

at static test

$M_{B_{test}} = 21$ kN.m

$\sigma_{b_{test}} = 75.5$ N/mm^2

margine $= 2.65$

at SWL.

$M_{B_{SWL}} = 15$ kN.m.

$\sigma_{b_{SWL}} = 54$ N/mm^2

margin $= 3.7$

2) Dynamic loads:

The dynamic test load = 1.2 S.W.L.

This test represents a check for the integrity of the lifting appliance.

After tests, when successfuly carriedout, the appliance is adjusted to tripout if the gets in excess of S.W.L.

CA is a simple beam,

$$\delta = \frac{P\ell^3}{48EI} \quad i.e \quad \frac{\delta}{\ell} = \frac{P\ell^2}{48EI_{xx}}$$

$$\frac{\delta}{\ell} \leqslant \frac{1}{700} \quad , \quad P_o = 1.4 * 15 = 21 \text{ kN}$$

$\ell = 4000$ mm, $E = 2.1 * 10^5$ N/mm²

$$\therefore I_{xx} \geqslant \frac{21 * 10^3 * (4000)^2}{48 * 2.1 * 10^5 * (1/700)} \geqslant 23.3 * 10^6 \text{ mm}^4$$

$\frac{\delta}{\ell} \leqslant \frac{1}{700}$

$P = 21$ kN

$I_{xx} \geqslant 2330$ cm⁴

The nearest are:

$I20 \longrightarrow I_{xx} = 2140$ cm⁴

$\boxed{I22 \longrightarrow I_{xx} = 3060 \text{ cm}^4}$

$I24 \longrightarrow I_{xx} = 4250$ cm⁴

Selected size I22

Properties of I22:

$\frac{220 * 98}{8.1 * 12.2}$, $I_{xx} = 3060$ cm⁴, $Z_{xx} = 278$ cm³

$I_{yy} = 162$ cm⁴, $Z_{yy} = 33.1$ cm³

$wt = 31.1$ kg/m′, $A = 39.5$ cm²

Expected deflection at Static test:

$$\delta^* \cong \frac{21 * 10^3 * (4000)^3}{48 * 2.1 * 10^5 * 3060 * 10^4} \cong 4.36 \text{ mm}$$

$$\frac{\delta^*}{\ell} = 1/918 < \frac{1}{700}$$

$\frac{\delta}{\ell} \cong \frac{1}{918}$

Note:

δ^* is considered approximate since the self weight is not included. Try to calculate the actual value by accounting for beam weight and the trolley weight

Acting Load & Load Condition	Point of Action	Pos. I R kN	Pos. I R_x	Pos. I R_y	Pos. II R kN	Pos. II R_x	Pos. II R_y	Pos. III R kN	Pos. III R_x	Pos. III R_y
unit load 1 kN	A B	Z	Z	Z	1.424	1.33	0.5	2.85	2.67	1.0
	O	1.0	Z	1.0	1.424	1.33	0.5	2.67	2.67	Z
Static load = SWL.*1.4 = 21 kN	A B				29.9	27.93	10.5			
	O				29.9	27.93	10.5			
1.2 * SWL. = 18 kN	A B	Z	Z	Z	25.63	23.94	9.0	51.3	48.06	18
	O	18.0	Z	18.0	25.63	23.94	9.0	48.06	48.06	Z
SWL = 15 kN	A B	Z	Z	Z	21.36	19.95	7.5	42.75	40.05	15
	O	15.0	Z	15.0	21.36	19.95	7.5	40.05	40.05	Z

Tie rod size :

From the tabulated values the maximum load on the tie rod occures when testing with 1.2 * SWL. load at position III. Hence, the tie rod and the connections at "A" and "B" Should be calculated for :

max. load = 51.3 kN acting along the tie rod centerline.

The critical section is the core area of the Lefthand or Righthand threads in connection with the turnbuckle. When adjusting the beam level under load, this core area is subjected to:

P_a (tension) = 51.3 kN

$P_a = 51.3\ kN$

$$T = 2T_1 = \left[P_a \frac{d_m}{2}\left(\frac{\tan\alpha + \mu'}{1-\mu'\tan\alpha}\right)\right] * 2$$

Size	M16x1.5	M18x1.5	M20x1.5	M22x1.5	M24x1.5	
d_i (mm)	14.052	16.052	18.052	20.052	22.052	
A_c (mm^2)	155	202	256	316	382	
$d_m = \frac{d_i + d_o}{2}$ (mm)	15	17	19	21	23	
$\tan\alpha = \frac{p}{\pi d_m}$	0.032	0.028	0.025	0.023	0.021	
$\tan\alpha + \mu' = X$	0.263	0.259	0.256	0.254	0.252	$\mu_{st/st} = 0.2$
$X \cdot d_m = Y$ (mm)	3.945	4.403	4.864	5.334	5.796	$\mu' = \frac{\mu}{\cos\beta} = 0.231$
$T = P_a \cdot Y$ (N.m)	202	226	250	274	297	Consider:
τ (N/mm^2)	371	271	216	173	141	$1-\mu'\tan\alpha \cong 1$
$\sigma = \frac{P_a}{A_c}$ (N/mm^2)	331	254	200	162	134	margin = 1.2
$\tau_c = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$	406	299	238	191	156	
$\sigma_y \geq$	812	598	476	382	312	
Material	50CrV4	(34Cr4) 37Cr4	(St.C55) St.C60	St 52-3 St.C45	St 52-3 St C35	St 52-3 DIN 17100

257.

<u>Notes</u>:

1) Materials bracketed have σ_y less than the required min. σ_y within 5% which is acceptable.

2) Selecting st. 52-3 is based on utilizing a cheap material since hardness and wear resistance are not functional.

For st. 52-3 : $16 < \Phi \leq 40$ $\sigma_{y_t} = 345\ N/mm^2$

<u>Forces on the post</u>:

Refer to table of forces acting at each position and find out that the extreme reactions on the post occure at a test load = 18 kN in pos. III :

- Tension in tie rod = 51.3 kN at B
  [horizontal component = 48.06 kN
  Vertical component = 18.0 kN]
- Reaction at O = 48.06 kN in horizontal direction.

$F_{Tie\ Rod} = 51.3$ kN

$R_O = 48.06$ kN.

Reations on the wall at B_1 and O_1 are

$$R_{B_1} = \frac{1}{(0.25+1.5+0.25)}\left[48.06 * 1.75 - 48.06 * 0.25\right]$$

$$\therefore \overleftarrow{R_{B_1}} = \overleftarrow{36.045}\ kN$$

$$R_{O_1} = \frac{1}{2}\left[48.06 * 1.75 - 48.06 * 0.25\right]$$

$$= \overrightarrow{36.045}\ kN$$

$\overleftarrow{R_{B_1}} = 36.045$ kN

$R_{O_1} = \overrightarrow{36.045}$ kN

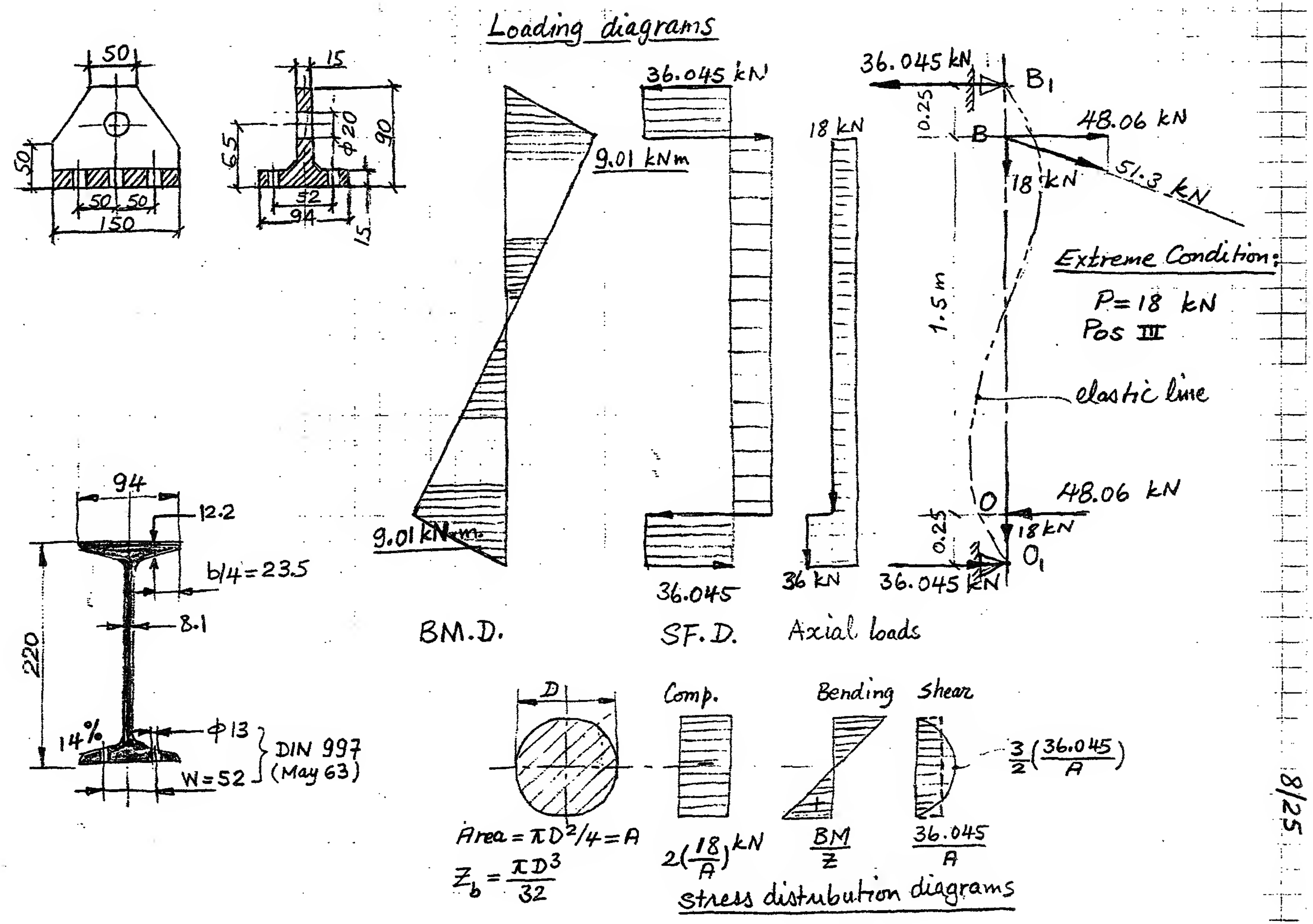
Maximum BM = 9.01 kN.m.

$BM_{max} = 9.01$ kN.m

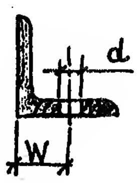
Post material is St 42, $\sigma_y = 220\ N/mm^2$
margin of safety = 1.5 (to have some rigidity)

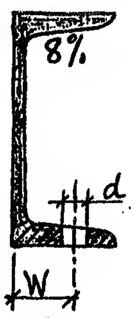
$$\therefore \frac{220}{1.5} = \frac{9.01 * 32 * 10^6}{\pi D^3}$$

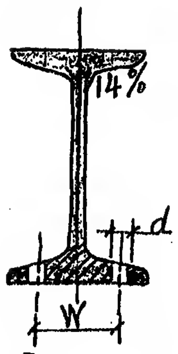
Material St 42



Loading diagrams
50
50
50 50
150
15
90
65
φ20
52
94
15
36.045 kN
9.01 kNm
9.01 kNm
BM.D.
36.045
SF.D.
18 kN
36 kN
Axial loads
36.045 kN
B1
B
0.25
48.06 kN
51.3 kN
18 kN
1.5 m
Extreme Condition:
P = 18 kN
Pos III
elastic line
O
48.06 kN
18 kN
O1
0.25
36.045 kN
94
12.2
b/4 = 23.5
8.1
220
14%
φ13
DIN 997 (May 63)
W = 52
D
Area = πD²/4 = A
Z_b = πD³/32
Comp.
2(18/A) kN
Bending
BM/Z
Shear
36.045/A
3/2 (36.045/A)
stress distubution diagrams







[DIN 997 May 1963] DIN 996 (April 1927)

Equal Angles Size	W	d	[W	[d	Nominal Size	I W	I d
3	17	8.5	20	11	4		
4	22	11	25	11	6½		
5	30	14	25	14	8	[22]	[6.4]
6	35	17	30	14	10	[28]	[6.4]
7	40	20	30	17	12	[32]	[8.4]
8	45	23	35	17	14	34 [34]	11 [11]
9	50	26	36	20	16	38 [40]	14 [11]
10	55	26	40	20	18	44 [44]	14 [13]
			40	23	20	46 [48]	17 [13]
			45	23	22	52 [52]	17 [13]
			45	26	24	56 [56]	17 [17]
			50	26	26	58 [60]	20 [17]
			50	26	(28)	62	20
			55	26	30	64	20
			55	26	(32)	70	20
			55	26	36	74	23
			55	26	(38)	80	23
			60	26	40	84	23

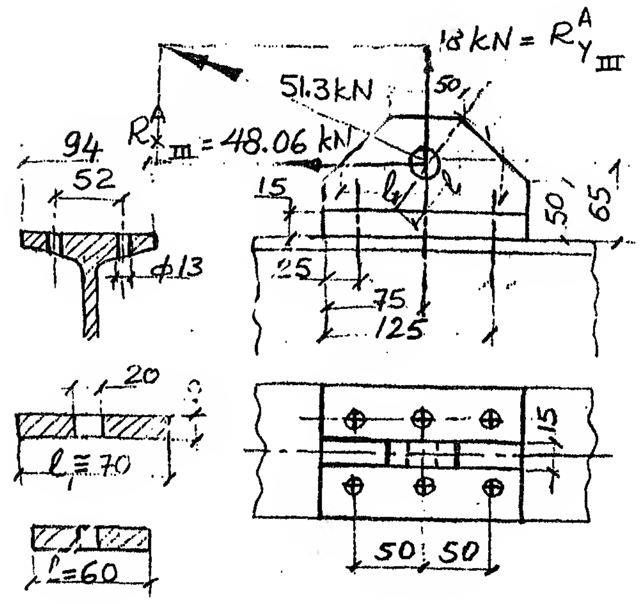
$\therefore \quad D = 85.5$ mm

This value represents the min. shaft diam.

$D \geq 85.5$ mm
post

Design of Joints :

1) Tie rod – Carrying beam connection:



(1-1) Pin diameter :

Calculated for double shear :

$$\tau = \frac{51.3 * 10^3}{2\,A} = \frac{2 * 51.3 * 10^3}{\pi\ d^2}$$

$R^A_{III} = 51.3$ kN

$$\tau = 0.6\,\sigma_y / 1.2 = \sigma_y / 2 \qquad \therefore d = \sqrt{\frac{2 * 2 * 51.3 * 10^3}{\pi\ \sigma_y}}$$

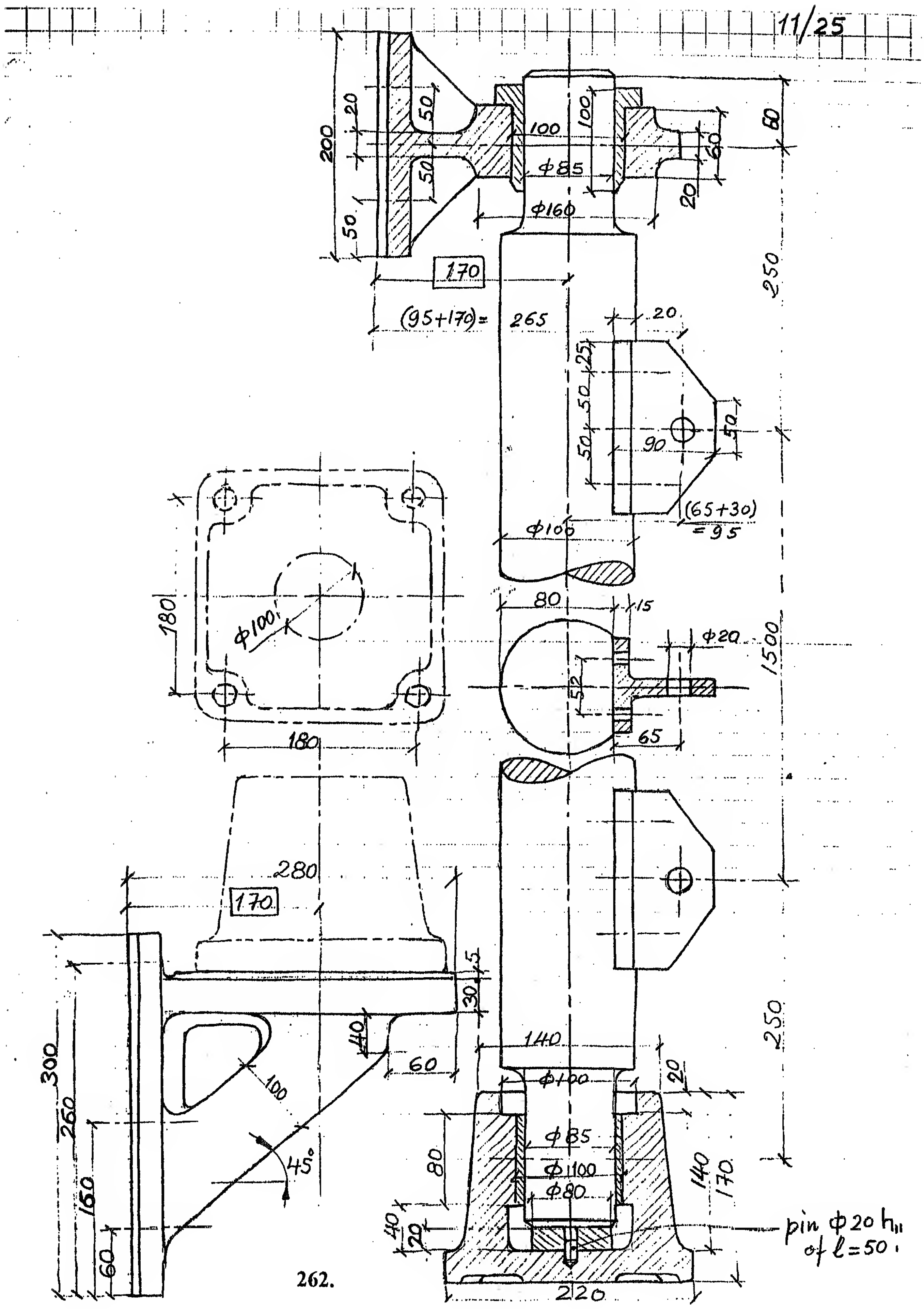
material	st 37	st 42	st 50
σ_y (N/mm^2)	200	220	250
$d \geq$ (mm)	18.1	17.2	16

Material: st 37

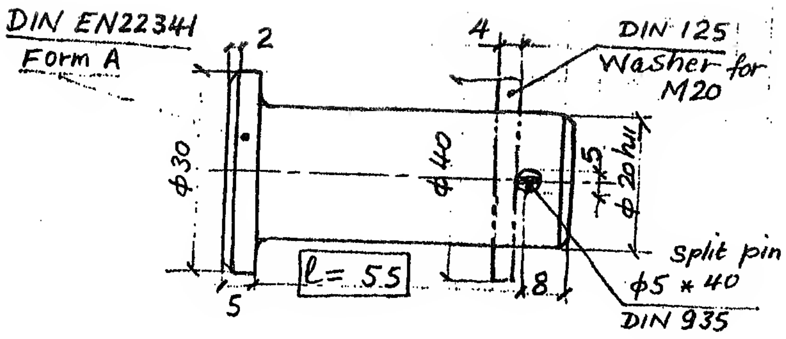
Pin diameter is taken 20 mm (h_{11})

Select basic shaft system h_{11}/H_{11}

$d = 20$ mm
h_{11}/H_{11}


200
20
50
50
50
100
100
φ85
φ160
60
80
20
170
(95+170)= 265
250
20
25
50
50
50
90
(65+30)
=95
φ100
80
15
φ20
52
65
1500
180
φ100
180
280
170
5
30
300
260
160
60
40
60
100
45°
140
φ100
20
φ85
φ100
φ80
80
140
170
40
20
220
250
pin φ20 h11
of l=50

262.



(1-2) Bracket Web:

Selected thickness is checked for crushing.

$$\sigma_{cr} = \frac{R^A_{III}}{d\,b} = \frac{51.3*10^3}{20*15} = 171 \quad N/mm^2$$

$\sigma_{cr} = 171\ N/mm^2$

$$\text{margin of Safety} = \frac{\sigma_y}{\sigma_{cr}} = \frac{200}{171} = 1.17$$

Note:

$\sigma_{cr} = (400 * BHN - 10{,}000)\ lb/in^2$ is an imperical formula for annealed carbon steel. in S.I. units:

$$\sigma_{cr} = \frac{400 * BHN - 10{,}000}{145.037}$$

$(1\ lb/in^2 \equiv 145.037\ N/mm^2)$

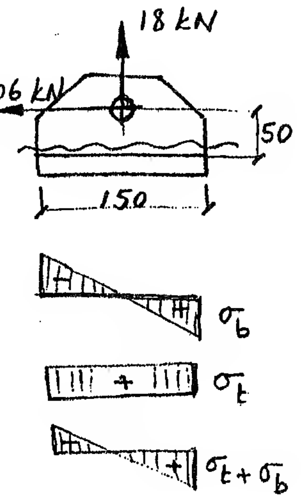
for St 37, BHN = 100 - 130 i.e min. BHN = 100

$$\therefore \sigma_{cr} = \frac{400*100 - 10{,}000}{\simeq 145} = 207 \quad N/mm^2$$

& the margin of safety $= \frac{207}{171} = 1.21$

margin = 1.21

(1-3) Flange-Web connection:



$$\sigma_b = \frac{48.06*10^3 * 50*6}{15*(150)^2} = 42.7 \quad N/mm^2$$

$$\sigma_E = \frac{18*10^3}{15*150} = -16 \quad N/mm^2$$

$$\sigma_{tor\,max} = 8 + 42.7 = 50.7 \quad N/mm^2$$

$$\sigma_{tot\,min} = 8 - 42.7 = -34.7 \quad N/mm^2$$

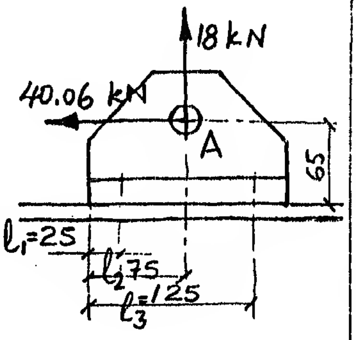
$\sigma_{b\,max} = 50.7\ N/m$

(1 - 4) Holding down bolts:

DIN 99 recommends hole diameter $\phi 13$ mm i.e the suitable bolt size is 12 mm diam. Six bolts M12 * 1.25 of high tensile steel. The high tensile bolt grade of steel to calculated. — 6 M12 x 1.25 mm

Core area = 92.1 mm^2

At the loading condition in load Pos III, a residual load estimated at 30% and will be applied to the calculated max. load per bolt. — $P_{res.} = 30\% \, F_{tot}$



Bracket "A"

a) the vertical load:

$$\text{Force per bolt} = \frac{18}{6} = 3 \ kN$$ — $F_v = 3 \ kN$

b) tension due to horizontal component:

$$2F_1/l_1 = 2F_2/l_2 = 2F_3/l_3$$

$$\frac{2F_1}{25} = \frac{2F_2}{75} = \frac{2F_3}{125} \quad \text{i.e} \quad F_1 = \frac{F_2}{3} = \frac{F_3}{5}$$

also:
$$40.06 * 65 = 2F_1 l_1 + 2F_2 l_2 + 2F_3 l_3$$
$$= 2\left(\frac{F_3}{5}\right) * 25 + 2\left(\frac{3F_3}{5}\right) * 75 + 2F_3 * 125$$
$$= (10 + 90 + 250) F_3 = 350 F_3$$

$$\therefore F_3 = \frac{40.06 * 65}{350} = 7.44 \ kN$$

$F_3 = 7.44$ kN
$F_2 = 4.46$ kN
$F_1 \cong 1.5$ kN

c) Shearing force:

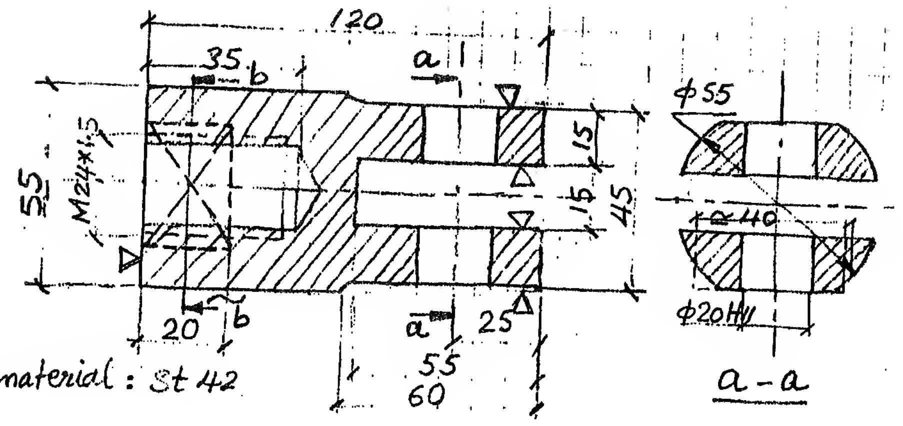
$$F_s = 40.06 \ kN.$$ — $F_{shear} = 40.06$ kN

$$F_{tot} \ (\text{normal}) = F_v + F_3 = 3 + 7.44 = 10.44 \ kN/\text{bolt}$$ — $F_{tot} = 10.44$

P_{axial} / bolt = 10.44 kN

& $P_{max} = 10.44 * 1.3 = 13.572$ kN./bolt — $P_{max} = 13.572$

2) Tie-rod forked connection:



material : St 42

Mat. St 42
$\sigma_y = 200\ N/mm^2$
$P = 51.3\ kN$

Load = 51.3 kN

section a-a is critical

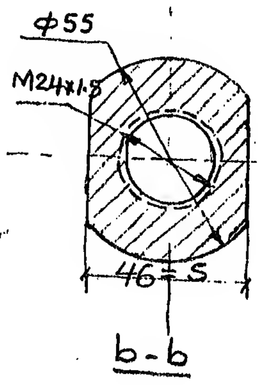
area $\cong 2[15*40-15*20]$

$\cong 600\ mm^2$

$\sigma_t = \dfrac{51.3*10^3}{600} = 85.5\ N/mm^2$

margin of safety $= \dfrac{\sigma_y}{85.5} = \dfrac{200}{85.5}$

$= 2.34$



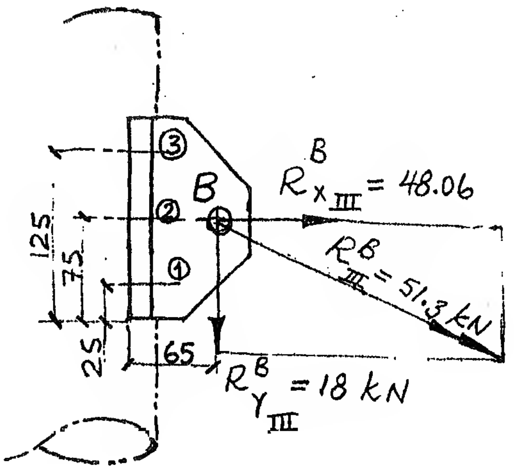
$\sigma_t = 85.5\ N/mm^2$
margin = 2.34

The same applies to the Forked end at "B"

③ Joint at "B":

The vertical component is 18 kN :

F_3^B, F_2^B, F_1^B are expected to be less than those at "A"



Since:

$$2F_1/\ell_1 = 2F_2/\ell_2 = 2F_3/\ell_3$$

i.e also: $F_1 = \frac{F_2}{3} = \frac{F_3}{5}$

and $18 * 65 = 2F_1^B \cdot \ell_1 + 2F_2^B \cdot \ell_2 + 2F_3^B \cdot \ell_3$

$= 350\, F_3^B$

$\therefore F_3^B = \frac{18 * 65}{350} = 3.343$ kN

$F_{horiz} = \frac{48.06}{6} = 8.01$ kN/bolt

F^B_{axial} /bolt $= 3.343 + 8.01 = 11.353$ kN

Per bolt:

$F_3^B = 3.343$ kN

$F_{horiz} = 8.01$ kN

$F^B_{axial} = 11.353$ kN

The shearing force = 18 kN is carried by the shaft shoulder.

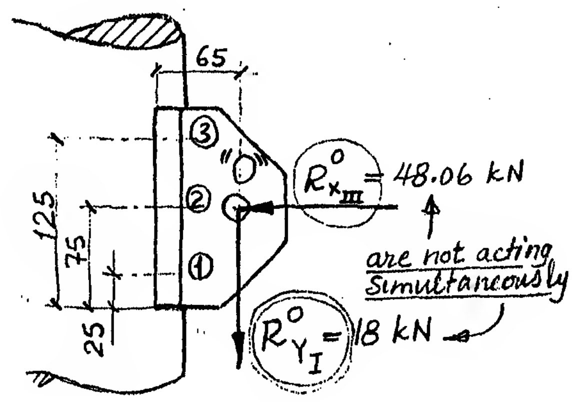
The tie-rod forked end at "B" is the same one used at "A" and the pin diam. and details also are the same.

④ <u>Joint at "O"</u>:

Due to $R^O_{Y_I} = 18$ kN,

$F_3^O = 3.343$ kN

While $R^O_{x_{III}} = 48.06$ kN pressing the bracket against the shaft releases the bolts free unless an axial load in the bolt due to initial assembly load is in excess of the share of each bolt

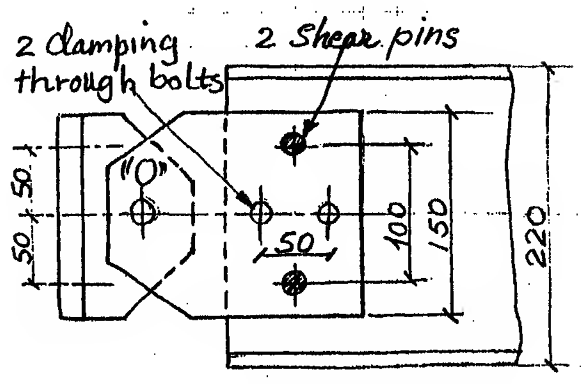


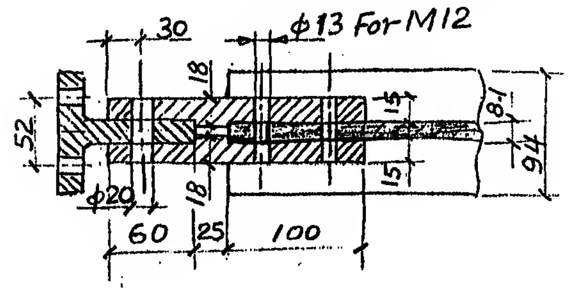
i.e. $P^O_{i_{axial}} > \frac{48.06}{6} > 8.01$ kN

$F_3^O = 3.343$ kN

$P^O_{i_a} > 8.01$ kN

(4-1) Bracket with I22 beam web:



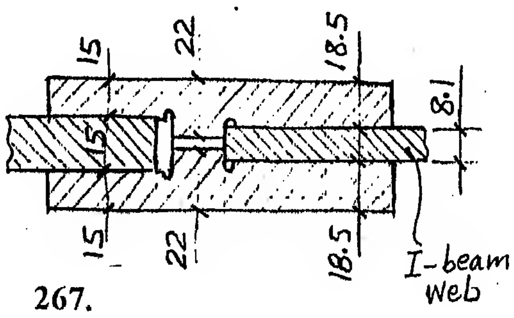


The hinge pin at "O" is subjected to a max. shearing force = 48.01 kN. This value is less than the shearing force at "A" (and "B") which is 51.3 kN. Hence the pin at "O" will be taken as that "A" in diameter (ϕ 20 h_{11}/H_{11}) and material (st 37) but the length (l = 50 mm).

Note:

For the sake of unification, i.e l = 55, the change the I-beam holding plates to be 22 original thickness each.

i.e l will be clamping a total thickness of 45 mm and l will be 55 mm.



(4-2) I-beam holding plates:

This joint on the I-beam web comprises:

- two shouldered plates.
- two shear pins.
- two clamping bolts.

and there are two max. loads:

a) $R^{o}_{x_{III}} = 48.06$ kN , a horizontal force when test load is in pos. III. This force is transmitted to the shear pin at "O" through two shoulders:

$R^{o}_{x_{III}} = 48.06$ kN

$$\sigma_{cr} = \text{force / crushed area} = \frac{48.06 * 10^3}{2(150) * (22-18.5)} \cong 48 \ N/mm^2$$

i.e. $\sigma_{cr} = 48 \ N/mm^2 < (\sigma_y / 1.2)_{st\,37}$

$\sigma_{cr} = 48 \ N/mm^2$

b) $R^{o}_{Y_I} = 18$ kN , a vertical force when test load is in pos. I. This force is transmitted to the holding plates through two shear pins (and secured by the tightening of two through bolts selected to be M12 * 1.25).

$R^{o}_{Y_I} = 18$ kN

$$\tau = \frac{18 * 10^3}{2[2 * \frac{\pi}{4}(d^2)]} \quad , \quad \tau \leq \frac{\tau_{y\ st\,37}}{1.2} \leq \frac{190 \times 0.6}{1.2}$$

$$\therefore d = \sqrt{\frac{18 * 10^3 * 1.2}{\pi * 190 * 0.6}} = 7.77 \text{ mm (for shear)}$$

$$\sigma_{cr} = \left(\frac{18 * 10^3}{2}\right) / (8.1 * d) \leq \frac{190}{1.2}$$

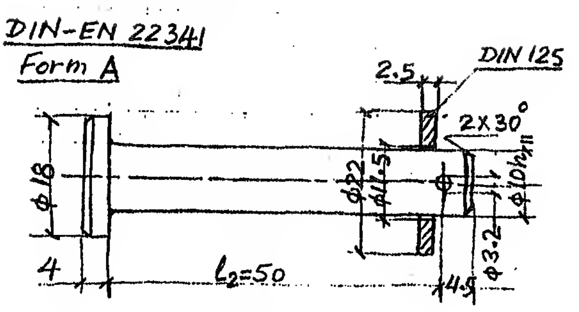
$$\therefore d \geq 7.02 \text{ mm (for crushing)}$$

The shear pin is taken $d = 10 \ h_{11}$ mm

2 Shear pins
$d = 10 \ h_{11}$ mm
$\ell_2 \geq 50$ mm

Note:
For the sake of unification, the two clamping bolts are taken M 12 x 1.25 mm., $\ell = 45 + V_2 = 45 + \left[\begin{smallmatrix}14\\16\end{smallmatrix}\right. = 60$ mm

2 bolts M12x1.2 with ordinary washer & nut, $\ell = 60$ mm



5) Pre-stressed bolts:

5-1) At Joint "A":

For M12X1.25 :

Core area = 92.1 mm²

$\therefore d_c = 10.83$ mm

$d_m = 11.414$ mm

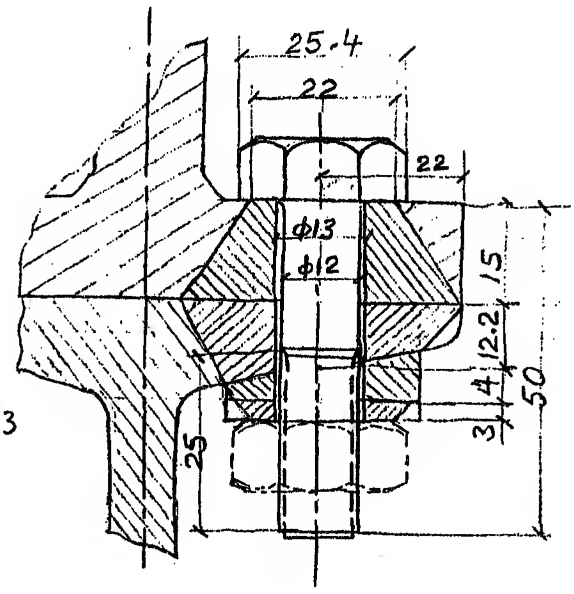
$\tan\alpha = \frac{p}{\pi d_m} = 0.035$

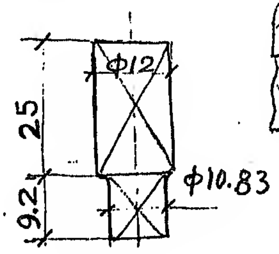
M 12 x 1.25

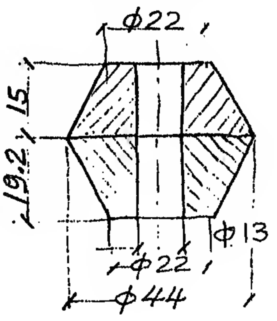
$d_c = 10.83$ mm

$d_m = 11.414$ mm

$\tan\alpha = 0.035$







$$\frac{1}{C_b} = \frac{1}{E}\left[\frac{25*4}{\pi(12)^2} + \frac{9.2*4}{\pi(11.414)^2}\right]$$

$$\therefore C_b = 6.754*10^5 \ N/mm$$

$C_b = 6.754*10^5$ N/mm

approximated $$\frac{1}{C_J} = \frac{1}{E}\left[\frac{\frac{4}{\pi}*15}{\left(\frac{22+44}{2}\right)^2 - 13^2} + \frac{\frac{4}{\pi}*19.2}{\left(\frac{22+44}{2}\right)^2 - 13^2}\right]$$

$$\therefore C_J \simeq 44.4*10^5 \ N/mm$$

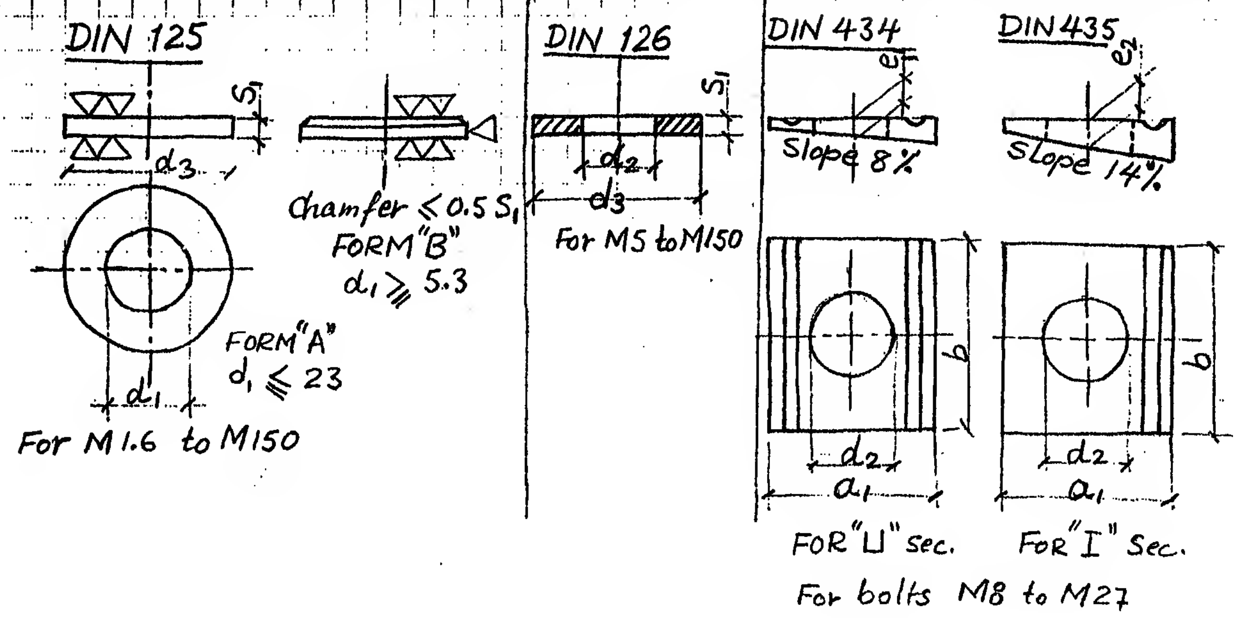
$C_J = 44.4*10^5$ N/mm

$$\frac{C_J}{C_b} = 6.6 \ , \ P_r = 0.3 P_{ext} \ , \ F^B_{axial} = 11.353 \ kN$$

$$\therefore \text{Consider} \quad P_i = P_{ext} + P_r = F^B_{axial} * 1.3 = 14.8 \ kN$$

$P_i = 14.8$ kN

Washers



d_1	d_2	d_3	a_1	b	e_1	e_2	S_1	Bolt diam.
3.2		7					0.5	3
3.7		8					0.5	3.5
4.3		9					0.8	4
5.3	5.5	10					1	5
6.4	6.6	12.5					1.6	6
7.4		14					1.6	7
8.4	9	17	22	22	2.9	3.05	1.6	8
10.5	11	21	22	22	2.9	3.05	2	10
13	14	24	30	26	4	4	2.5	12
17	18	30	36	32	4.5	5	3	16
21	22	37	44	40	5	6	3	20
23	24	39	50	44			3	22
25	26	44	56	56	6	7	4	24
28	30	50	56	56			4	27
31	33	56	62	62	6.5	7.5	4	30

Tightening Torque $= T_1 + T_2$

$$T_1 = 14.8\left(\frac{11.414}{2}\right)\left[\frac{0.035+0.23}{1-0.23*0.035}\right] -$$

$\therefore T_1 = 22.383$ kN. mm

$$T_2 = P_a \frac{dm_{seat}}{2} \cdot \mu_{seat}$$

$$= 14.8\left[\frac{22+13}{2*2}\right] * 0.2 = 25.9 \text{ kN. mm}$$

$$T = 22.383 + 25.9 = 48.283 \text{ kN.mm}$$

$$\sigma = \frac{14.8*10^3}{92.1} = 160.7 \text{ N/mm}^2$$

$$\tau = \frac{16*22.383*10^3}{\pi(10.83)^3} = 89.74 \text{ N/mm}^2$$

$$\tau_{comb} = \frac{1}{2}\sqrt{(160.7)^2+4(89.74)^2} = 120.5 \text{ N/mm}^2$$

$$\tau_y = 120.5 * 1.3 = 156.6 \text{ N/mm}^2$$

$$\sigma_y = \frac{\tau_y}{0.6} \geqslant 261 \text{ N/mm}^2$$

Select high tensile steel grade 8.8

$P_{ax} = 14.8$ kN
$\mu' = 0.23$
$\tan\alpha = 0.035$

$T_1 = 22.383$ kN. mm

$T_2 = 25.9$ kN. mm

$T = 48.3$ kN.mm

$\sigma = 160.7$ N/mm^2

$\tau = 89.74$ N/mm^2

$\tau_{comb} = 120.5$ N/mm^2

$\sigma_y \geqslant 261$ N/mm^2

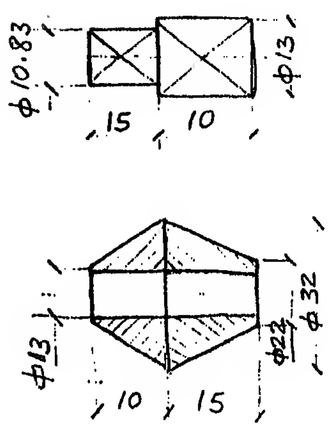
Material h.t. bolts 8.8

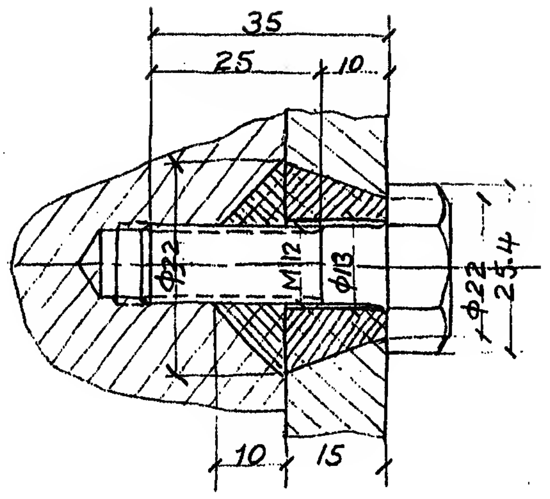
Notes:

1- The high tensile steel bolts grade 8.8 is the commercially used grade. Other grades when specified, either of lower or higher grades, are considered special order and will be more expensive.

2- The tightening torque of 22.4 kN.mm (2.3 kg m) is used for all the bolts for the sake of unification.

5-2) At "B" and "O" :





$$\frac{1}{C_b} = \frac{4}{\pi E}\left[\frac{10}{(13)^2} + \frac{15}{(10.83)^2}\right]$$

$$C_b = 8.82 * 10^5 \ N/mm$$

$$\frac{1}{C_J} = \frac{4}{\pi E}\left[\frac{15}{\left(\frac{22+32}{2}\right)^2 - 13^2} + \frac{10}{\left(\frac{13+32}{2}\right)^2 - 13^2}\right]$$

$$C_J = 29.22 * 10^5 \ N/mm$$

Plotting the characteristic lines of bolt and joint, one can find :

Since max load on bolt $= P^o_{iax} + P_r = 10.51$ kN
where $P_r = 2.5$ kN

$\therefore \ P_i = 4.5$ kN

$$T_1 = 4.5\left[\frac{11.414}{2}\left(\frac{0.035 + 0.23}{1-(0.23*0.035)}\right)\right] \cong 6.81 \ kN.mm$$

$$T_2 = 4.5\left[\frac{22+13}{2\times 2}\right](0.2) = 7.875 \ kN.mm$$

Tightening torque = 14.685 kN.mm
For wrench arm = 300 mm
$\therefore$ human effort = 48.95 N ($\simeq$ 5 kg)

$R^o_{x_{III}} = 48.06$ kN
$P^o_{iax} = 8.01$ kN
$P_r = 0.3 P_e$
$\approxeq 2.5$ kN

$C_b = 8.82 * 10^5$ N/mm

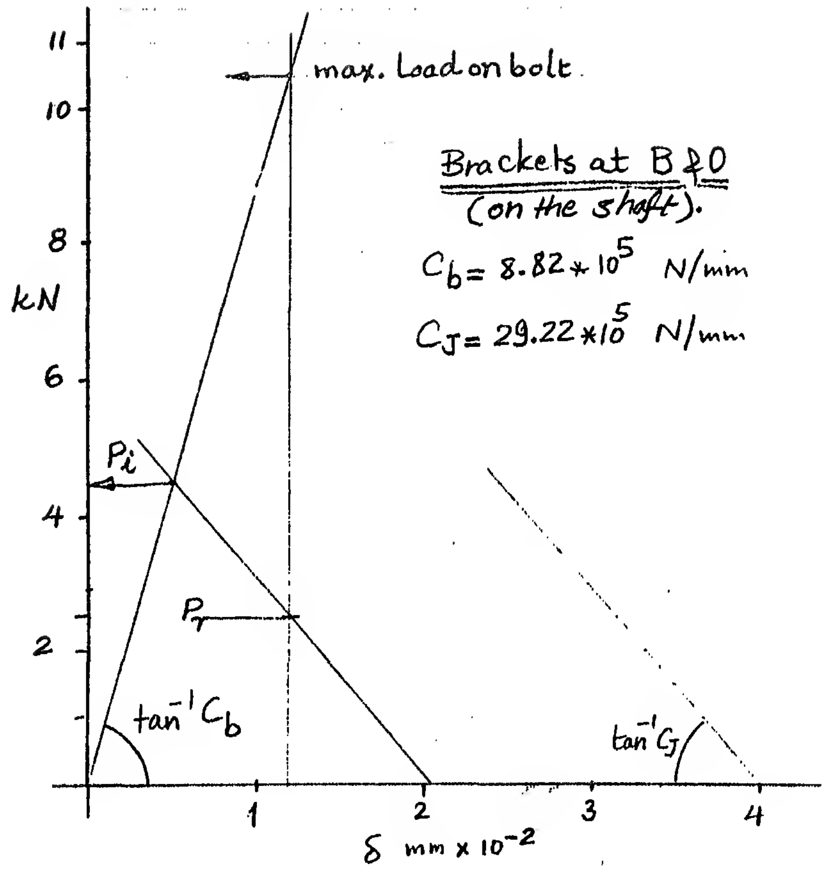
$C_J = 29.22 * 10^5$ N/mm

$P_i = 4.5$ kN

$\frac{\mu}{\cos\beta} = \frac{0.2}{\cos 30^o} = 0.23$

$T_1 = 6.81$ kN.m.

$T \simeq 15$ kN.mm



Assembly state of stress:

$P_{axial} = 4.5$ kN , $T_1 = 6.81$ kN.mm

$$\therefore \sigma = \frac{4500}{92.1} = 48.86 \text{ N/mm}^2$$

$$\tau = \frac{16 * 6810}{\pi (10.83)^3} = 27.3 \text{ N/mm}^2$$

$$\tau_{comb} = \frac{1}{2}\sqrt{(48.86)^2 + 4(27.3)^2} = 36.6 \text{ N/mm}^2$$

Working state of max. stress:

$P_{axial} = 10.5$ kN

$$\sigma_t = \frac{10.5 * 10^3}{92.1} = 114 \text{ N/mm}^2$$

$$\sigma_y > 114 * 1.3 \geqslant 148 \text{ N/mm}^2$$

Assembly stress

$P_{axial} = 4.5$ kN

$T_1 = 6.81$ kN. mm

$\sigma = 48.86$ N/mm^2

$\tau = 27.3$ N/mm^2

$\tau_{comb} = 36.6$ N/mm^2

Working stress

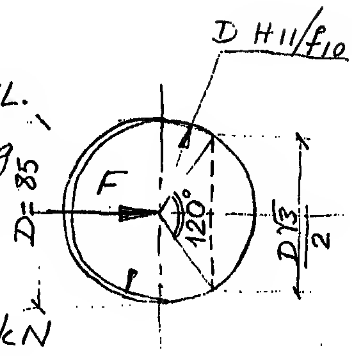
$\sigma_t = 114$ N/mm^2

$\sigma_y \geqslant 148$ N/mm^2

6- Post ends and wall brackets:

6-1) Top end bearing :-

During test, test load = 1.2 S.W.L. will result in crushing the bearing bush. Check for bearing pressure should be based on S.W.L. i.e for a load $= \frac{36.05}{1.2} = 30.04$ kN



$85\ H_{11} = 85^{+0.220}_{\ 0.000}$
$85\ f_{10} = 85^{-0.036}_{-0.176}$
$\ell = 100$ mm
$F = 30.04$ kN

$$p = \text{Bearing pressure} = \frac{30.04 * 10^3 * 2}{100 * 85 * 1.732} = 4.1\ N/mm^2$$

$p = 4.1\ N/mm^2$

The bush material is selected to be gray C.I. which has an allowable bearing pressure of 12 N/mm². i.e. the bush will have an extended life.

Material
gray C.I.

6-2) lower end bearings :-

Radial:

$F_{radial} = 30.04$ kN
$D = 85\ H_{11}/f_{10}$ also
$\ell = 80$ mm.

$$\text{Bearing pressure} = \frac{30.04 * 10^3 * 2}{85 * 85 * 1.732} = 4.8\ N/mm^2$$

The bush material is gray C.I.

$F_{rad} = 30.04$ kN
$D = 85$ mm
$\ell = 80$ mm
$p = 4.8\ N/mm^2$

Axial: $F_{axial} = 18/1.2 = 15$ kN (= S.W.L.)

Total axial load = 2 * 15 kN

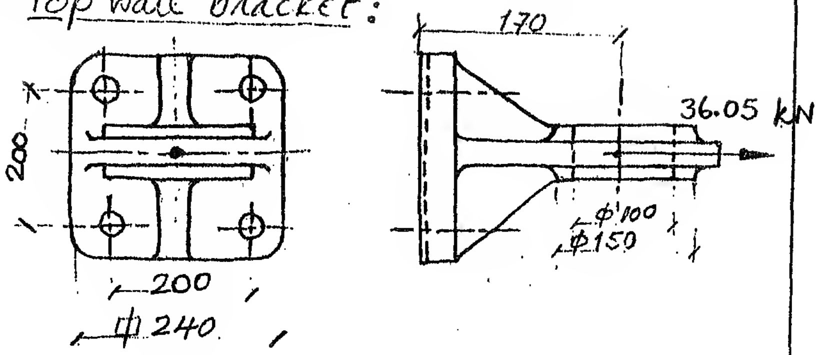
Disc dims.: $D = 80$ mm, $d = 20$, $h = 20$ mm

$$\text{bearing pressure} = \frac{2 * 15 * 10^3}{\frac{\pi}{4}(80^2 - 20^2)} = 6.36\ N/mm^2$$

Disc material is selected as gray C.I

$F_{axial} = 30$ kN
$D = 80$ mm
$d = 20$ mm
$p = 6.36\ N/mm^2$
Material
Gray C.I.

6-3) Top wall bracket:



The maximum force acting at B_1 is 36.05 kN. The bracket is bolted by 4 bolts, i.e. the force per bolt $= \frac{36.05}{4} = 9.01$ kN.

This load/bolt together with a residual load is estimated to be 14.8 kN ($P_{res.} \cong 5.8$ kN which is more than 60%) and the tightening torque will be taken 48.3 N.m. for a bolt size M12×1.25 whose material is H.T.S. grade 8.8.

Force / bolt = 9 kN

$P_{ex} + P_r = 14.8$ kN

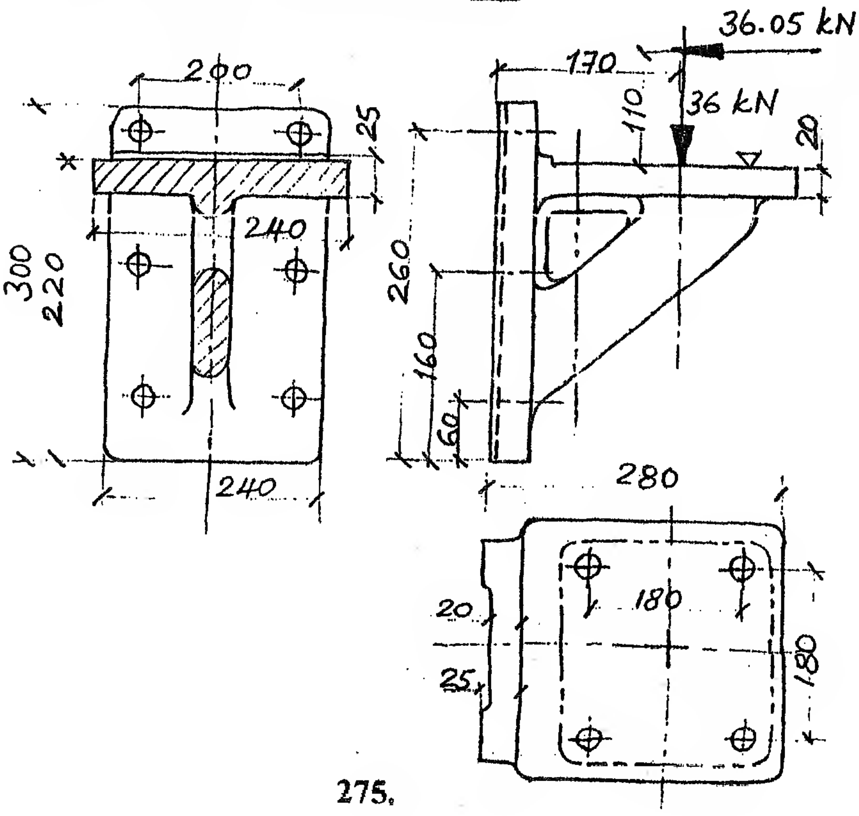
Bolt size M12×1.25

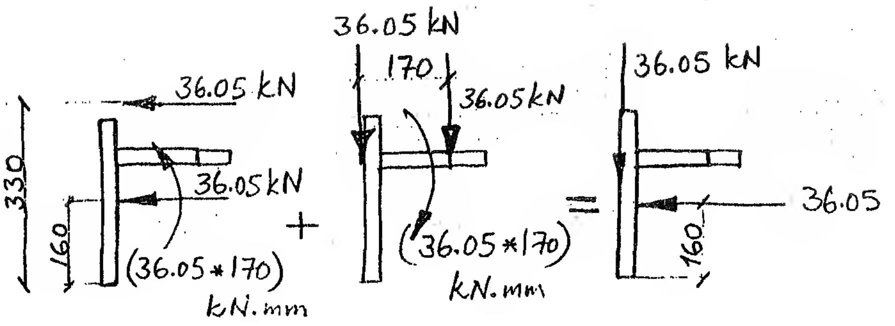
T = 48.3 N.m.

Bolt material H.T.S. grade 8.8

6-4) Lower wall bracket:

$R_{O_1} = 36.05$ kN





One can see that there is no moment acting on the bracket. If we use the same bolts M12x1.25 of grade 8.8 tightened with T= 48.3 N.m, the axial force in each of the six bolts = 14.8 kN

∴ The total force pressing the bracket to the wall is given by

$$P_{tot_{test}} = 6 * 14.8 + 36.05 = 124.85 \text{ kN}$$

also

$$P_{tot_{working}} = 6 * 14.8 + 30 = 118.8 \text{ kN}$$

for $\mu_{st/st} = 0.15$ (min. value for dry friction)

∴ Limit of friction force (test) $= \mu P_{tot_{test}} = 0.15 * 124.85 = 18.73$ kN

6 bolts
M12x1.25
T = 48.3
Grade 8.8

$P_{tot_{test}} = 124.85$ kN
$P_{tot_{working}} = 118.8$ kN
$\mu = 0.15$

Required vertical resisting force = 36.05 kN

∴ A shear plate (or dowel pin if possible) is needed to resist a min force of: 36.05 − 18.73 = 17.32 kN

Note :

It is possible to use a friction material of a very thin thickness on condition that the friction coefficient $\geq \frac{36.05}{124.85} * 1.2 \geq 0.35$

required $\mu_o \geq 0.35$

The 1.2 factor is a Security factor.

However, in a lifting equipment, a positive & not passive means (like friction) are recommended.